mation about the plastic behavior). With this method nano hardnesses can be determined. The resolution depth and load measurement determine the accuracy (taking into account the Buckle rule). Considerable effects can be expected from the surface roughness, the coating uniformity (e.g. small droplets) and the real indentor geometry. One cannot assume that the nano indentor has the theoretical shape. The standards are described in ISO TR 14577 and in DIN 50359, parts 1 to 3.

Modulus: The elastic modulus quantifies elastic properties of the coating. Young's modulus can be determined by accoustic microscopy, Brillouin scattering or bending tests. There are no standards for these methods. In principle the slope of the unloading curve in the universal hardness experiment can be used to derive the elastic modulus, see above. Recently a laser accoustic technique has been developed for determination of the elastic modulus, see [11,12]. A German pre-standard is described in DIN V 32939. The surface wave dispersion phase velocity is measured as a function of frequency. Frequencies up to 200 Mhz allow reliable measurements of the e-modulus fore film thicknesses less than 50 nm. The results show remarkable agreement with those obtained from depth sensing indentation.

Mechanical Properties: Roughness

One of the most important factors influencing the decorative impression of a product is the surface topography. Generally the PVD coating has no levelling effect, and the roughness prior to PVD deposition is reproduced after deposition. The testing methods for PVD are not different from test methods for uncoated surfaces. A short description of a few methods follows.

Contact Methods for Roughness Measurement

Surface roughness measurements with a contact stylus are currently the most widely used industrial method. Several devices are commercially available and suitable for different measuring ranges (with a vertical resolution of 10 nm). A load is applied to the stylus when traversing the surface. The vertical movements of the stylus are used to trace surface roughness. Most commonly used are the parameters Ra (average of the absolute distance between middle value and actual surface) and Rz (average of the peak to bottom maximum of 5 different measurement tracks). A major disadvantage of the method is that the dimension of the stylus influences the measurement. A major advantage is that the method is well characterized and quantifiable for given stylus geometires. The tests are described in ISO 468-1982, ISO 5436, ISO 4287, DIN ISO 4288, DIN ISO 3274.

Non-Contact Optical Methods for Roughness Measurement

Many of the optical methods use a laser beam for illumination. In autofocus detection systems this laser beam is used as an optical stylus moving over the surface. A wide aperture objective focusses the beam onto the surface, the reflected light from the surface is collected with a photo detector which receives maximum signals when the surface is at the focal point. When the laser beam is out of focus the intensity change is registered and used to control the movement of the objective until the focal point is reached again. The vertical movements of the objective are used as a measure for detecting the surface profile. The lateral resolution is determined by the diameter of the laser beam and the wave length of used light. The method is not yet standardized.

To get information about surface topography in the nanometer scale the Atomic Force Microscope (AFM) is often used. AFM measures repulsive forces between a surface and a flexible cantilever with a silicon nitride tip. ~~The interatomic~~ forces between the tip and the surface deflect the cantilever. The movements of the cantilever are used as a measure for the surface profile. The vertical resolution of the AFM is in the 0.01 nm range. The method is not yet standardized.

Wear Resistivity of ceramic PVD coatings is generally much higher than that of Organic Coatings. Therefore the standard test method for Organic Coatings by falling abrasive _D 968-93) should not be used for ceramic PVD coatings like brass coloured ZrN or TiN. A wear test that can be used there is e.g. the Tabor Abrasor test as described in D 4060-95. Recommended values to be achieved by standard ceramic PVD coatings are that the Tabor Abrasor test is performed for over 500 to 1000 cycles, depending on the type of abrasive wheels.

Decorative Properties

Colour: The colour of PVD coatings is established with methods similar to normal uncoated objects. The most widely used system is the CIELAB colour system. Basically colours are characterized by three parameters:

a* and b* defining a plane with colours ~~ranging from green~~ (-a*), to red (a*) and blue (-b*) to yellow (b*). The L* value is used to indicate the contribution of white light, black (L*=0) and white (L*=100). The colour distance ΔE^*_{ab} is given by: $\Delta E^*_{ab} = \sqrt{((L1^*-L2^*)^2 + (a1^*-a2^*)^2 + (b1^*-b2^*)^2)}$

Depending on the application colour differences in between 5 and 16 are acceptable. With a proper PVD process colour reproducibility can be achieved within $\Delta E_{ab} = 3$. See Figure 1.

The colour is normally measured with the test sample facing the colour detector, and the light source at 45° relative to the sample surface (test method 45/0). Important settings are the illumination source (e.g. D65), aperture and observer angle (2° or 10°).